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COMMUNICATION/NAVIGATION OUTAGE FORECASTING SYSTEM (CNOFS)

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Interim Report

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This report has been approved for publication.

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14. ABSTRACT
The CNOFS satellite is a DoD Space Test Program mission utilizing AFRL, NASA, Aerospace and NRL payloads designed to enable forecasting and nowcasting of ionospheric irregularities that adversely impact communication, navigation and surveillance systems. The CNOFS satellite is currently undergoing environmental testing at General Dynamics. The CNOFS Satellite is on track for launch in mid 2005 from the Kwajelein Atoll.

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INTRODUCTION

The Communication / Navigation Outage Forecasting System (C/NOFS) is a satellite development program to demonstrate a technique for locating and forecasting scintillations in the ionosphere. Scintillations are random fluctuations in signal phase and amplitude that develop when radio waves pass through ionospheric electron density irregularities as they propagate to a receiver. Scintillations are responsible for decreased satellite-to-ground message throughput and delayed signal acquisition. C/NOFS will alert users of impending UHF and L-band satellite communication outages, GPS navigation degradations, and radar tracking errors.

MISSION

The goal of the C/NOFS satellite is to detect regions of active scintillation, to forecast regions of scintillation 3 to 6 hours before its onset, and to improve estimates of scintillation probability. During the C/NOFS mission, the estimates will extend to 24 hours from the time of the data collection. With the knowledge gained from the mission, the estimates may be extended to 48 to 120 hours. This mission will be accomplished by exploiting extensive satellite and ground-based observations along with a program of focused theoretical investigations and data analysis to forecast the equatorial scintillations.

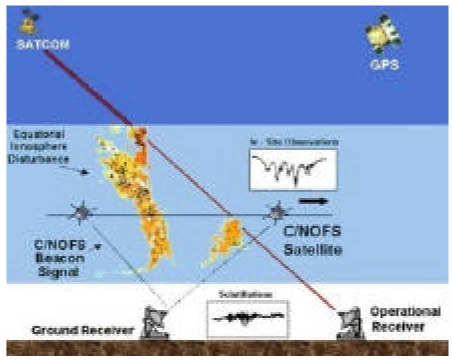

Figure 1. *Artist's Conception of C/NOFS Mission.*

APPROACH

C/NOFS consists of three core components: a dedicated low-altitude, low-inclination satellite instrumented to monitor the equatorial ionosphere continuously around the globe; a network of ground receivers to monitor scintillation conditions; and the C/NOFS Data Center at Hanscom AFB where data from space and ground-based sensors are combined with first principle models of the global ionosphere to generate forecasting and nowcasting products.

C/NOFS is a joint project of the Department of Defense (DoD) Space Program (STP) and the Air Force Research Laboratory (AFRL). Program participants include the National Aeronautics and Space Administration (NASA), The Naval Research Laboratory (NRL), NASA's Goddard Space Flight Center, University of Texas, the Aerospace Corporation; all of which supplied instrument packages integrated on a General Dynamics satellite bus.

The six on board instrument packages are:

- Vector Electric Field Instrument (VEFI)
- Planar Langmuir Probe (PLP)
- Ion Velocity Meter (IVM)
- Neutral Wind Meter (NWM)
- C/NOFS Occultation Receiver for Ionospheric Sensing and Specification (CORISS)
- Coherent Electromagnetic Radio Tomography (CERTO)

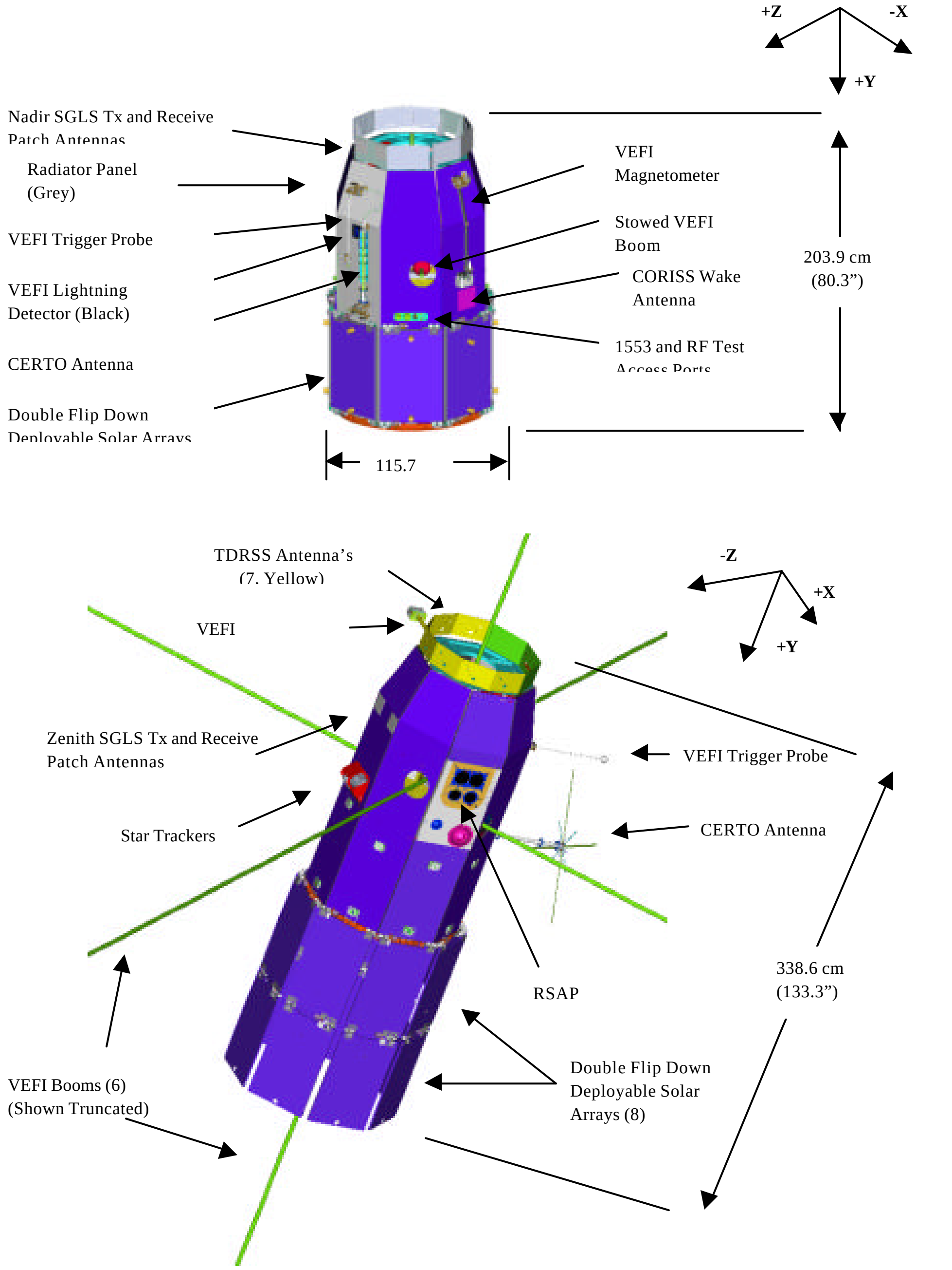

Figure 2. C/NOFS External Configuration with Undeployed (Top) and Deployed (Bottom) Solar Arrays and Payload Booms

C/NOFS INSTRUMENTS

The payload or sensors onboard the C/NOFS satellite will provide information required to establish global ionospheric forecasts. C/NOFS will orbit the earth in an elliptic orbit between 375 and 710 km in altitude at 13° inclination. This orbit keeps the satellite on magnetic field lines with apex altitudes of $\leq$ 800 km approximately half the time, and within the ionospheric equatorial anomaly regions for most of its orbit.

Vector Electric Field Instrument (VEFI)

VEFI is a NASA GSFC instrument designed 1) to investigate the role of the ambient electric fields and the neutral wind and plasma density in initiating nighttime ionospheric density depletions and turbulence; 2) to determine the very low frequency electric fields associated with abrupt, large amplitude, density depletions and 3) to quantify the spectrum of the wave electric fields and plasma densities associated with ESF. The VEFI instrument includes a vector electric field double probe detector, a Langmuir trigger probe, a flux gate magnetometer, a lightning detector and associated electronics. The heart of the instrument is the set of double probe detectors designed to measure DC and AC electric fields using 6 identical, mutually orthogonal, deployable 9.5 m booms tipped with 10 cm diameter spheres containing embedded preamplifiers. The booms are oriented perpendicular to the plane of the orbit and +/- 45 degrees from the ram and wake directions to avoid perturbation of the ambient E field measurements by the wake of the satellite.

Planar Langmuir Probe (PLP)

The PLP instrument was designed and built by the Air Force Research Laboratory, Space Vehicles Directorate to measure total in-situ plasma density, density fluctuations, electron temperature and vehicle charging effects. The instrument contains two separate sensors: an open probe and a gridded probe. The open, or surface-mounted, probe measures both positive (ion) and negative (electron) current. The open probe is a small square of circuit board material that has two concentric circles etched into it. This gives a center circle of copper surrounded by an electrically isolated concentric ring of copper. A variable bias voltage is applied to the electrodes. The current collected by the center circle is conditioned, logarithmically amplified and digitized. The collected current is directly related to the ion density, the collecting area and the spacecraft velocity. The gridded probe, in contrast, has a current collecting surface that is recessed beneath the outer surface of the instrument. Three fine metal grids cover the collecting surface and are used to eliminate fringing fields into the plasma, to reject electrons in favor of ions, and to measure the energy distribution of the ions.

Ion Velocity Meter (IVM)

IVM is part of the Coupled Ion Neutral Dynamics Investigation (CINDI) conducted by the University of Texas at Dallas and sponsored by the NASA Explorer program. The IVM provides vector ion drift velocity measurements for speeds up to 1000 m/s to an accuracy of approximately 5 m/s to aid in specifying the impact and duration of ionospheric disturbances. The ion drift vector is derived from the two sensors that comprise the IVM instrument. One sensor measures two mutually perpendicular components of the ion drift perpendicular to the sensor look direction (the Ion Drift Meter or IDM) and the other sensor measures the ion drift along the sensor look direction (the Retarding Potential Analyzer or RPA). The sensors are designed to view in the space vehicle RAM direction. In this configuration, ions moving supersonically at approximately the spacecraft velocity enter the sensor apertures.

Neutral Wind Meter (NWM)

The NWM is also part of the Coupled Ion Neutral Dynamics Investigation (CINDI) conducted by the University of Texas at Dallas and sponsored by the NASA Explorer program. It consists of a cross-track sensor and an in-track (RAM) wind sensor designed to measure the neutral wind velocity vector. Both sensors present apertures to the RAM direction and detect the RAM energy of the neutral gas along the sensor look direction and the angle of arrival of the gas with respect to the sensor look direction. The in-track (RAM) wind sensor delivers the in-track neutral wind component from an energy analysis of the incoming neutral beam.

C/NOFS Occultation Receiver for Ionospheric Sensing and Specification (CORISS)

The CORISS sensor is a dual frequency Ground Positioning Sensor (GPS) receiver built by the Aerospace Corporation. It is capable of measuring differential group and phase delays associated with signals transmitted by satellites in the GPS constellation. Accurate ionospheric electron density profiles can be inferred from these measurements when GPS satellites are occulted by the Earth's limb as viewed by C/NOFS. Observations of ionospheric scintillation at GPS frequencies along both occulting and non-occulting GPS links are also possible.

The C/NOFS CORISS instrument components consist of a GPS receiver electronics box, a wake antenna, a pre-selection filter, and flexible, low loss GORE cabling connecting the electronics box, filter, and antenna. The CORISS receiver communicates with the spacecraft via a 1553 Interface Electronics Box. The Interface Box also performs some autonomous control functions for the CORISS receiver.

When power is applied to the CORISS receiver, it automatically begins to search, acquire, and track all GPS satellites in view. CORISS makes pseudo range, phase and signal to noise ratio (SNR) observations of the GPS L1 (1.575 GHz) and L2 (1.227 GHz) signals.

Coherent Electromagnetic Radio Tomography (CERTO) and Ground Receivers

The primary purpose of CERTO is to measure the Total Electron Content (TEC) of the ionosphere and to use these TEC data to reconstruct electron densities using computerized tomography. The reconstructions will provide electron density images and radio wave scattering maps in planes containing the satellite and linear arrays of receivers on the ground. The secondary purpose of CERTO is to determine the presence of ionospheric irregularities by observing phase and amplitude scintillations in radio signals propagating from the onboard CERTO transmitter to receivers on the ground.

The CERTO instrument consists of a multiple frequency radio beacon on the C/NOFS satellite transmitting continuous emissions at 150.012, 400.032, and 1066.752 MHz. The beacon antenna illuminates the earth where the beacon receivers are located. Several ground receivers use the differential phase technique with pairs of frequencies to determine the integrated electron concentration (i.e., TEC) along the straight-line path to the satellite. The ground receiver also records phase fluctuations that can be converted into a scintillation index. The TEC data from the receivers taken during the over flight of the satellite is collected and processed to yield ionospheric density parameters.

C/NOFS DATA CENTER

Located at Hanscom AFB, the Data Center will use C/NOFS data along with corroborative data from other ground and space based sources (receivers for GPS, UHF scintillation, and satellite beacons) to create an assimilative model of the ionosphere. This initial condition of the ionosphere is then integrated forward in time to create predictions. Ground-based instruments most relevant to the C/NOFS mission include

incoherent scatter radars, coherent scatter radars, digital ionosondes, magnetometers, Fabry-Perot interferometers, GPS receivers and optical imagers. A first-principles approach to modelling will be used and consists of a suite of models, including ionospheric assimilation, ambient forecasting, and scintillation models, for generating physics-based forecasts of day to day variability of the ionosphere.

CONCLUSION

The C/NOFS satellite is a DoD Space Test Program mission utilizing AFRL, NASA, Aerospace and NRL payloads designed to enable forecasting and nowcasting of ionospheric irregularities that adversely impact communication, navigation and surveillance systems. The C/NOFS satellite is currently undergoing environmental testing at General Dynamics. The C/NOFS Satellite is on track for launch in mid 2005 from the Kwajelein Atoll into a low inclination (13°), elliptical (~ 375 x 710 km) orbit aboard a Pegasus XL launch vehicle. Once operational, C/NOFS will be the first satellite solely dedicated to forecasting ionospheric irregularities and radio wave scintillations.

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